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Reference values for quantitative left ventricular and left atrial measurements in cardiac computed tomography

Stolzmann, P ; Scheffel, H ; Leschka, S ; Schertler, T ; Frauenfelder, T ; Kaufmann, P A ; Marincek, B ;
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Abstract To assess reference values for left ventricular (LV) and left atrial (LA) dimensions, global LV function, and LV-myocardial mass for cardiac CT. We examined 120 subjects undergoing a coronary angiography using 64-slice and dual-source CT. All individuals had a low cardiovascular risk, normal ECG, negative biomarkers, and a normal cardiac CT examination. All subjects had a negative medical history of cardiovascular disease both on admission and at clinical 6-month follow-up. The following measurements were obtained: septal wall thickness (SWT), posterior wall thickness (PWT), LV inner diameter (LVID), LA anterior posterior diameter (LAD_{sys}), end-systolic volume (ESV), and end-diastolic volume (EDV), LV-myocardial mass (LVMM). We found significant gender-related differences for all LV

dimensions (SWT_{sys}, SWT_{dia}, PWT_{sys}, PWT_{dia}, LVID_{sys}, LVID_{dia}). LAD_{sys} showed no significant difference between males and females. Significant differences were found for global LV functional parameters including ESV, EDV, and SV, whereas no significant differences were found for the EF. LV-myocardial mass parameters showed significant gender-related differences. No significant correlation was found between any of these parameters and age. All data were transferred to percentile ranks. This study provides gender-related reference values and percentiles for LV and LA quantitative measurements for cardiac CT and should assist in interpreting results.

Keywords Computed tomography · Left ventricle · Left atrium · Reference values

Introduction

The assessment of cardiac chamber dimensions, ventricular function, and myocardial mass represents an important component for the diagnosis of cardiac disease, for risk stratification, and therapeutic decision making, and is of high prognostic value in patients with ischemic and non-ischemic cardiomyopathy [1, 2].

Recent advances in multi-detector row computed tomography (CT) technology have continuously increased the role of the non-invasive technique for imaging of coronary arteries [3–7]. Actually, patients with stable angina pectoris and inconclusive electrocardiogram (ECG) or stress test are

recommended to have a CT coronary angiography [8, 9]. Since coronary artery imaging with CT is performed with ECG gating, images in multiple phases throughout the cardiac cycle are obtained that allow depiction of the left ventricle (LV) in diastole and systole and quantification of global LV function with similar accuracy when compared to magnetic resonance imaging (MRI) [10–13]. Similarly, detailed anatomic data about the size and shape of the left atrium (LA) are obtained that correlate well with results from echocardiography [14].

Normal ranges of LV and LA dimensions, global LV function, and myocardial mass have been established in healthy individuals for echocardiography [15–17] and for

MRI using steady-state free precession [18, 19] and gradient echo sequences [18, 20, 21]. However, CT studies on LV and LA dimensions are still lacking, and reference values of LV and LA dimensions, global LV function, and myocardial mass parameters have not yet been defined for cardiac CT. This appears particularly intriguing, because cardiac CT is increasingly used, and it provides data about chamber dimensions and functions as a spin-off from each CT coronary angiography examination, without increasing the amount of radiation or administered contrast media to the patient. In addition, since slight but systematic differences between CT and MRI measurements of global LV volumes and function have been repetitively shown [22], the need for modality-specific reference values is further enhanced. The purpose of this study was to establish gender-specific reference values for LV and LA dimensions, global LV function, and LV myocardial mass for cardiac CT.

Materials and methods

One hundred and twenty individuals including 67 female patients (mean age 57.0 ± 9.5 years, range 40–70 years) and 53 male patients (mean age 54.1 ± 8.3 years, range 40–70 years) who had undergone a clinically indicated cardiac CT coronary angiography between January 2005 and October 2006 were retrospectively included in this study. Reasons for referral were atypical chest pain with negative ECG negative and biomarkers on admission in all individuals. The medical history was available in all subjects and included information about cardiovascular risk factors such as a positive family history, hyperlipidemia, diabetes mellitus, nicotine abuse, and arterial hypertension.

We selected normotensive (blood pressure $<140/90$ mmHg) individuals with sinus rhythm who had a low pre-test probability of coronary artery disease (based on the Framingham criteria [23]). All individuals had no abnormalities in previous echocardiographies (which was available in 19 subjects), and all had no history of cardiac disease (i.e., myocardial infarction, cardiac surgery, or intervention). Patients were included when their Agatston score was below the 25th age- and gender-matched percentile [24], and in whom coronary artery stenoses (in this study defined as any vessel diameter reduction) could be reliably excluded with CT coronary angiography. Conventional catheter angiography was not considered clinically indicated in any subject of the population.

Exclusion criteria were ECG abnormalities, any medication, history of arterial hypertension, and obesity [body mass index (BMI) >30 kg/cm²]. CT exclusion criteria were allergy to iodine-containing contrast medium and nephropathy (serum creatinine level >150 μ mol/l).

Patients were followed-up by chart reviews for 6 months. Patients requiring repeat cardiovascular testing over this period, suffering from death from any cause, from cardiac death, non-fatal myocardial infarction, unstable angina, recurrent chest pain, or coronary revascularization were excluded. On subsequent clinical follow-up sessions, chest pain was referred to as musculoskeletal in nature ($n=88$) or as caused by gastrointestinal disorders ($n=32$).

Cardiac multi-detector row CT

Cardiac CT examinations were obtained on a 64-slice CT system (Somatom Sensation 64; Siemens Medical Solutions, Forchheim, Germany) in 33 individuals using the following scanning parameters: tube current-time product 650 mAs, tube voltage 120 kV, slice collimation 32×0.6 mm, slice acquisition 64×0.6 mm by means of a z-flying focal spot, gantry rotation time 330 ms, pitch 0.2, reconstructed slice thickness 1 mm (increment 0.75 mm), using a soft tissue convolution kernel (B30f). A dual-source CT system (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany) was used in 87 individuals using the following CT parameters: tube current-time product 350 mAs/rotation, tube voltage 120 kV, slice collimation $2 \times 32 \times 0.6$ mm, slice acquisition 64×0.6 mm by means of a z-flying focal spot, gantry rotation time 330 ms, pitch 0.20–0.53 (depending on the heart rate), reconstructed slice thickness 0.75 mm (increment 0.5 mm), using a soft tissue convolution kernel (B26f).

All images were acquired during mid-inspiration with the subjects in a supine position and elevated arms. No beta-blockers for heart rate control were given prior to CT in any patient.

With 64-slice CT, 80 ml of iodixanol (Visipaque 320, 320 mg/ml, GE Healthcare, Buckinghamshire, UK) followed by 30 ml saline solution was injected into an antecubital vein via a 18-gauge catheter (injection rate 5 ml/s). With dual-source CT, a two-phasic contrast media protocol (first phase: 60–80 ml contrast, second phase: same amount as first phase with 20% contrast medium and 80% saline solution) was used that was adjusted to the varying scan duration. Bolus tracking was used with both CT systems for initiating the main data acquisition as soon as the attenuation in the ascending aorta reached the threshold of 120 Hounsfield units. Data acquisition was performed in a cranio-caudal direction from the tracheal bifurcation to the diaphragm. ECG-gated tube pulsing for radiation dose reduction was used in all examinations. ECG-gated pulsing was switched on at 60% of the R-R interval when 64-slice CT was employed. With dual-source CT, the ECG-pulsing window was adapted according to the heart rate, as previously recommended [25].

CT image reconstruction

In the 64-slice CT system the adaptive cardiac volume approach was used for image reconstruction. This approach automatically switches between one- and two-segment reconstructions depending on the patient's heart rate. Scanning with dual-source CT was performed in a mono-segment reconstruction mode [26]. Retrospective ECG-gating was used to synchronize data reconstruction with the ECG, and images were reconstructed in increments of 5% steps from 0% to 95% of the RR interval. All data were post-processed on a second Wizard (Siemens Medical Solutions) equipped with cardiac post-processing software (Syngo Circulation, Siemens Medical Solutions). The estimated radiation doses using these CT protocols were approximately 11 mSv for 64-slice CT [27] and 7–9 mSv for dual-source CT [28].

CT data analysis

End-systolic and end-diastolic phases were visually identified by one experienced reader on multi-planar reformations (MPR). End-systole was visually defined as the phase with smallest LV volume; end-diastole was defined as the phase with largest LV volume. Measurements in end-systole and end-diastole of the specific parameters were taken at the same orientation and level. The following measurements were obtained:

(1) LV dimensions

All measurements of LV dimensions were obtained at the chorda level and were performed according to the international recommendations for chamber quantification in echocardiography [17].

- Septal wall thickness in end-systole (SWT_{sys}) and end-diastole (SWT_{dia}) was measured on short-axis MPR in the orientation of the four-chamber plane (Fig. 1).
- Posterior wall thickness in end-systole (PWT_{sys}) and end-diastole (PWT_{dia}) was measured on short-axis MPR in the orientation of the four-chamber plane (Fig. 1).
- LV inner diameter in end-systole ($LVID_{sys}$) and end-diastole ($LVID_{dia}$) was measured in the four-chamber MPR (Fig. 1).
- Relative wall thickness (RWT) was calculated using the formula: $RWT = 2 \times PWT_{dia} / LVID_{dia}$

(2) LA dimension

- LA anterior posterior diameter in end-systole (LAD_{sys}) was measured on axial oblique MPR through the level of the aortic valve and parallel to the LV outflow tract in a strictly anterior-posterior orientation (Fig. 2). Confluences of pulmonary veins were excluded, as previously recommended [17].

(3) Global LV function

LV epicardial and endocardial contours were semi-automatically detected by the software; the contour detection was visually checked and manually corrected if considered necessary (Fig. 3). Papillary muscles were included in the LV cavity. The following global LV functional parameters were calculated:

- End-systolic volume (ESV)
- End-diastolic volume (EDV)
- Stroke volume (SV) by using the formula $SV = EDV - EDV$
- Ejection fraction (EF) by using the formula $EF[\%] = SV \times 100 / EDV$

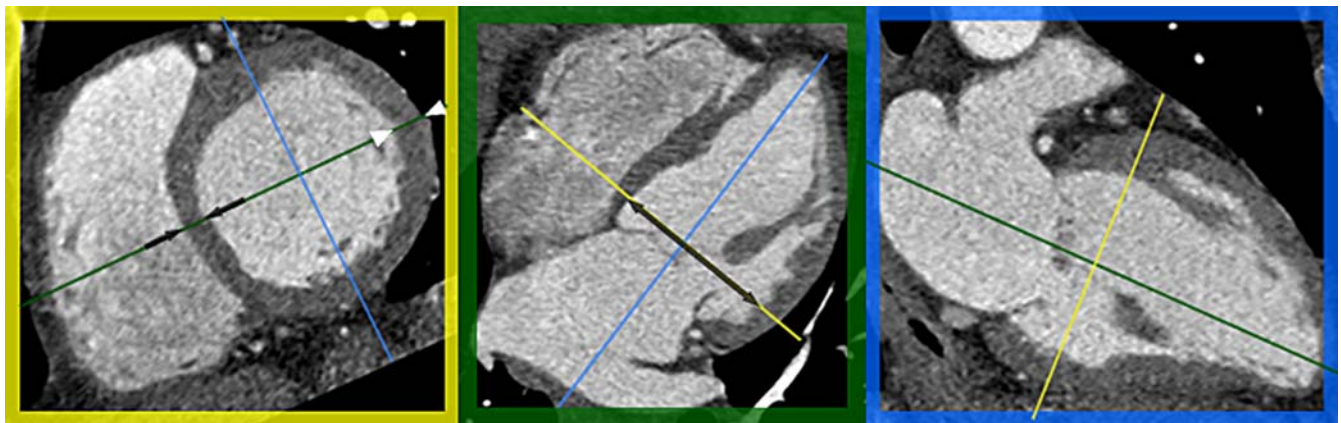


Fig. 1 Multi-planar reformations of a cardiac CT examination at end-diastole. Short-axis reformation (yellow box) was defined perpendicular to the long-axis. Septal wall thickness (SWT, black arrows) and posterior wall thickness (PWT, white arrowheads) measurements were obtained at the chorda level. Four-chamber reformation (green box) shows left ventricle and left atrium as well

as right ventricle and right atrium at the mid-ventricular level. Black arrow indicates left ventricular inner diameter (LVID). Two chamber reformation (blue box) demonstrates the long axis (green line) defined from the mid-level of the mitral valve to the apex of the left ventricle

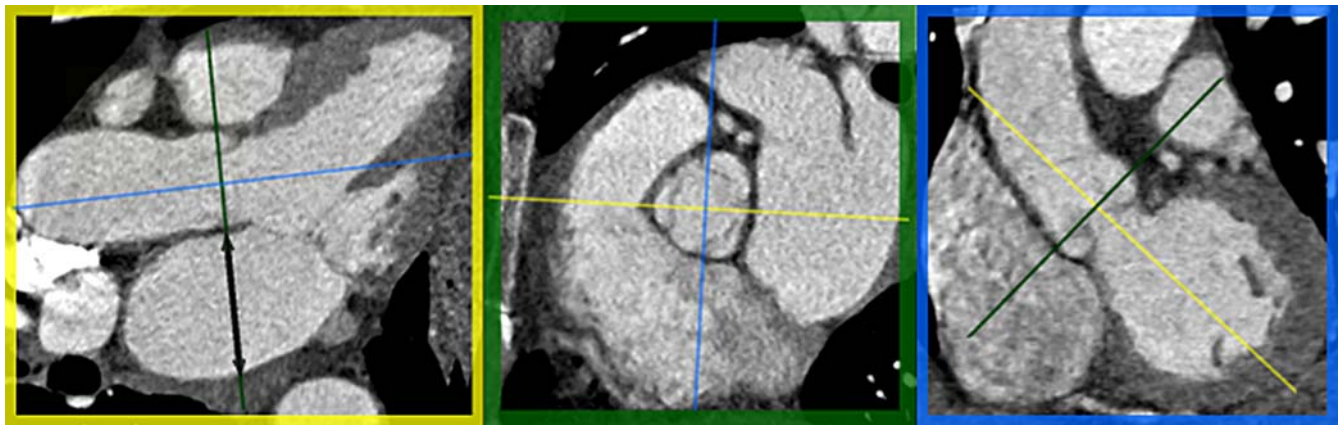


Fig. 2 Multi-planar reformations of a cardiac CT examination at end-systole. Axial-oblique reformation (yellow box) was defined to show the long-axis and to run through the mid-level of the aortic

valve, parallel to the LV outflow tract (blue line). The left atrium in the anterior-posterior orientation is visualized (green box). Left atrial diameter (LAD) was measured in the same orientation (black arrow)

4) LV myocardial mass parameters

- LV myocardial mass (LVMM) by using the formula $LVMM = (\text{epicardial myocardial volume} - \text{endocardial myocardial volume}) \times 1.04 \text{ g/ml}$ (Fig. 3).
- LV myocardial mass index (LVMMI) was calculated by the formula $LVMMI = LVMM/BSA$ (BSA being the body surface [29]).

To test for inter-observer variability of left heart measurements, data from 25 subjects (7 from the 64-slice CT group, 18 from the dual-source CT group, representing the distribution to the two scanners) were independently analyzed by a second reader using the same criteria mentioned above. To test for intra-reader variability, the first reader re-analyzed the same 25 studies after 6 weeks. Both the intra-reader variability and the inter-reader variability were low (Table 1); therefore, the remaining 95 individuals were evaluated by only one reader.

Statistical analysis

All quantitative variables are described as mean \pm standard deviation. The data were descriptively reviewed and statistically analyzed using Kolmogorov-Smirnov's to test for normality. Student's t-test for independent samples was used to test for CT system- and gender-specific differences. Univariate analysis of variances with post hoc Bonferroni correction was used to compare groups of different age decades. Correlation between dual-source CT measurements and age was tested through Pearson's linear regression. Inter- and intra-reader variability was tested using the concordance correlation coefficient. Percentiles were calculated from the standard normal table, representing the probability of a score occurring. P values <0.05 were considered statistically significant. Data analysis was performed using commercially available software (SPSS 12.0, Chicago, IL; MedCalc 9.0.2, Mariakerke, Belgium).

Fig. 3 Multi-planar reformations of a cardiac CT examination indicating epicardial (green lines) and endocardial (red lines) contours of the left ventricle in end-systole in the short-axis (left) and long-axis (right). Epicardial and endocardial volumes were calculated for global left ventricular function and left ventricular myocardial mass

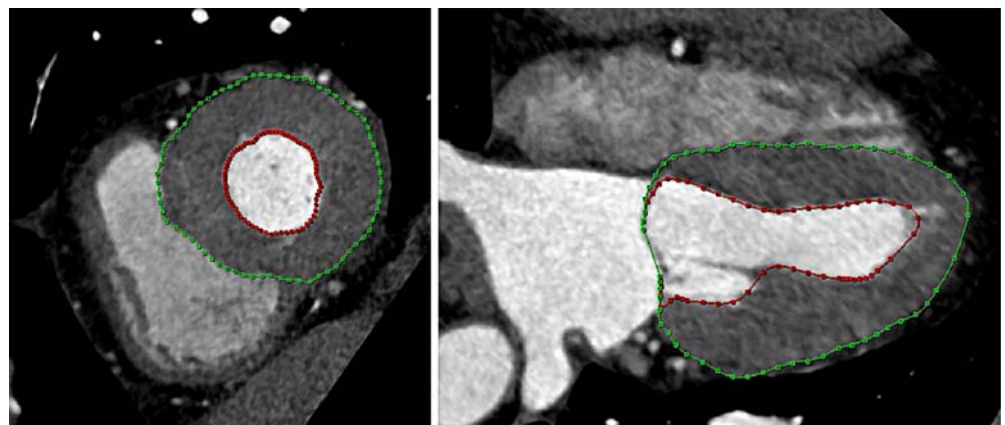


Table 1 Concordance correlation coefficients for inter- and intra-reader variability (n=25)

	Parameters	Inter-reader	Intra-reader
LV dimensions	Septal wall thickness, SWT _{sys}	0.79	0.82
	Septal wall thickness, SWT _{dia}	0.84	0.80
	Posterior wall thickness, PWT _{sys}	0.86	0.89
	Posterior wall thickness, PWT _{dia}	0.86	0.84
	LV inner diameter, LVID _{sys}	0.81	0.79
	LV inner diameter, LVID _{dia}	0.86	0.83
LA dimension	LA anterior-posterior diameter, LAD _{sys}	0.91	0.86
Global LV function	End-systolic volume, ESV	0.95	0.88
	End-diastolic volume, EDV	0.93	0.89
LV myocardial mass parameters	LV myocardial mass, LVMM	0.97	0.98

LV: left ventricle, LA: left atrium, sys: end-systole, dia: end-diastole

Results

All measurements could be obtained in each patient. Mean heart rate was 59.3 ± 4.6 bpm (range 47–64 bpm) in patients undergoing 64-slice CT, and was 72.7 ± 17.4 (range 44–89 bpm) in the patients undergoing dual-source CT. The mean BMI in men was $23.7 \text{ kg/cm}^2 \pm 2.8$ (range 18.5–29.8 kg/cm^2) with a mean BSA of $1.94 \pm 0.19 \text{ m}^2$ (range 1.53–2.38 m^2). Mean BMI in women was $22.8 \text{ kg/cm}^2 \pm 2.7$ (range 17.6–27.7 kg/cm^2) with a mean BSA of $1.78 \pm 0.19 \text{ m}^2$ (range 1.41–2.03 m^2).

All quantitative variables except the heart rate showed a normal distribution. No significant gender-specific differences were found for the age, heart rate, and BMI. Significant gender-specific differences were found for the BSA ($P < 0.05$).

Comparisons of all dimensional (SWT_{sys}, $P = 0.23$; SWT_{dia}, $P = 0.37$; PWT_{sys}, $P = 0.47$; PWT_{dia}, $P = 0.81$; LVID_{sys}, $P = 0.72$; LVID_{dia}, $P = 0.96$; LAD_{sys}, $P = 0.57$), functional (ESV, $P = 0.24$; EDV, $P = 0.52$; EF, $P = 0.20$), and LV mass parameters (LVMM, $P = 0.35$; LVMMI, $P = 0.14$) between 64-slice CT and dual-source CT showed no significant differences. Thus, data from both CT systems were pooled for subsequent analysis. Similarly, no significant differences between patients undergoing 64-slice CT or dual-source CT were found for BMI and BSA.

Table 2 displays parameters and P values for gender-specific comparisons. Significant differences between men and women were found for all parameters of LV dimensions, including SWT_{sys}, SWT_{dia}, PWT_{sys}, PWT_{dia}, LVID_{sys}, LVID_{dia}, and RWT. LAD_{sys} showed no significant differences between males and females. Significant differ-

Table 2 Descriptive characteristics (mean and SD) of LV and LA dimensions, global LV function, and LV myocardial mass in males and females with P values for gender-specific comparisons

	Parameters	Males (n=53)		Females (n=67)		P values
		Mean	SD	Mean	SD	
LV dimensions	Septal wall thickness, SWT _{sys} [cm]	1.3	0.2	1.1	0.2	<0.05
	Septal wall thickness, SWT _{dia} [cm]	0.9	0.2	0.8	0.1	<0.05
	Posterior wall thickness, PWT _{sys} [cm]	1.5	0.3	1.4	0.2	<0.05
	Posterior wall thickness, PWT _{dia} [cm]	0.9	0.2	0.8	0.2	<0.05
	LV inner diameter, LVID _{sys} [cm]	2.9	0.5	2.8	0.4	<0.05
	LV inner diameter, LVID _{dia} [cm]	4.5	0.5	4.4	0.5	<0.05
	Relative wall thickness (RWT)	0.42	0.11	0.38	0.08	<0.05
	LA anterior posterior diameter, LAD _{sys} [cm]	3.5	0.5	3.4	0.5	0.46
LA dimension	LA anterior posterior diameter, LAD _{sys} [cm]	3.5	0.5	3.4	0.5	0.46
	LA anterior posterior diameter, LAD _{sys} [cm]	3.5	0.5	3.4	0.5	0.46
Global LV function	End-systolic volume, ESV [ml]	47	19	40	12	<0.05
	End-diastolic volume EDV [ml]	144	38	115	7	<0.05
	Stroke volume, SV [ml]	95	29	76	18	<0.05
	Ejection fraction, EF [%]	66	9	66	7	0.89
LV myocardial mass parameters	LV myocardial mass, LVMM [g]	167	38	129	29	<0.05
	LV mass index, LVMMI [g/m ²]	86	18	68	13	<0.05

LA: left atrium, LV: left ventricle, dia: end-diastole, sys: end-systole, SD: standard deviation

ences were found for global LV functional parameters, including ESV, EDV, and SV, whereas no significant differences were found for the EF. LV myocardial mass parameters (i.e., LVMM and LVMMI) showed significant differences between male and female patients.

Percentiles of LV and LA dimensions, global LV functional parameters, and LV myocardial mass parameters are shown for males in Table 3 and for females in Table 4.

Individuals were grouped according to age decades, with group I ranging from 40–49 years ($n=30$), group II ranging from 50–59 years ($n=45$), and group III ranging from 60–70 years ($n=45$). A significant difference was found for SWT_{sys} between subgroups II and III in women ($P<0.05$). No other significant differences between all subgroups and for all other parameters were found.

LV and LA dimensions did not significantly correlate with age, testing males and females separately. Global LV functional parameters showed no significant correlation with age; only the SV showed a trend towards reduction with increasing age in women ($r=-0.22, P=0.07$). No significant correlation was found between age and both LV myocardial mass parameters.

Discussion

Cardiac CT is an emerging investigation that has already entered daily clinical routine in many institutions. With each cardiac CT, auxiliary data about left heart size, volumes, and myocardial mass are obtained that should be provided to the referring physician in addition to the information about the presence or absence of coronary artery disease.

Ethical concerns about radiation dose and potentially nephrotoxic contrast medium administration are the two

most likely dilemmas why CT reference values of left heart measurements in healthy individuals have not yet been assessed. These two inherent shortcomings of CT will not be resolved in the near future. In this study, we tried to approach a normal, healthy population by including only normotensive subjects with sinus rhythm having a low risk of cardiovascular disease, no obesity, no history of cardiac disease, no electrocardiography or biomarker evidence of cardiac disease, no medication, and no evidence of cardiac disease at the 6-month follow-up. In addition, coronary artery disease was reliably excluded with CT coronary angiography in all subjects of this study. By doing so, our study is the first—to the best of our knowledge—that provides normal cardiac CT reference values of left heart measurements allowing the definition of the limit between normal and disease states. Transmitting the principles of echocardiography [17] to CT, the reference values provided in this study for RWT combined with LVMMI permit the identification of LV remodeling and characterization of concentric or eccentric hypertrophy (Fig. 4).

All data from this study showed a normal distribution and could be therefore transformed to gender-related percentiles. These are clinically easy to handle and allow for the assignment of quantitative left heart measurements. The percentile rank stratifies absolute quantitative left heart measures and allows flexible thresholds to be set that account for the independent effect of gender [24]. In general, reference values are bound by two limits and contain 95% of the values found in healthy individuals. In order to define an increase or decrease of any parameter, the 2.5th and the 97.5th percentile value should be taken as threshold. Gender-specific values have to be taken into account, because differences exist in LV morphology and function between men and women [20].

Table 3 Percentiles for LV and LA dimensions, global LV function, and LV myocardial mass parameters in males

	Parameters	2.5th	10th	25th	50th	75th	90th	97.5th
LV dimensions	Septal wall thickness, SWT_{sys} [cm]	0.8	1.0	1.1	1.3	1.5	1.6	1.7
	Septal wall thickness, SWT_{dia} [cm]	0.6	0.7	0.8	0.9	1.0	1.1	1.2
	Posterior wall thickness, PWT_{sys} [cm]	1.0	1.2	1.4	1.5	1.7	1.9	2.1
	Posterior wall thickness, PWT_{dia} [cm]	0.6	0.7	0.8	0.9	1.0	1.2	1.3
	LV inner diameter, $LVID_{sys}$ [cm]	2.1	2.4	2.7	3.0	3.3	3.6	3.9
	LV inner diameter, $LVID_{dia}$ [cm]	3.6	3.9	4.2	4.5	4.8	5.2	5.5
	Relative wall thickness (RWT)	0.20	0.28	0.35	0.42	0.49	0.56	0.64
LA dimension	LA anterior posterior diameter, LAD_{sys} [cm]	2.6	2.9	3.2	3.5	3.8	4.2	4.5
Global LV function	End-systolic volume, ESV [ml]	9	22	34	47	60	72	85
	End-diastolic volume EDV [ml]	70	95	119	144	170	193	219
	Stroke volume, SV [ml]	37	57	75	95	114	132	152
	Ejection fraction, EF [%]	48	54	59	66	72	77	83
LV myocardial mass parameters	LV myocardial mass, LVMM [g]	92	118	141	167	192	215	241
	LV mass index, LVMMI [g/m^2]	51	63	74	86	98	109	121

LV: left ventricle, LA: left atrium, sys: end-systole, dia: end-diastole

Table 4 Percentiles for LV and LA dimensions, global LV function, and LV myocardial mass parameters in females

Parameters		2.5th	10th	25th	50th	75th	90th	97.5th
LV dimensions	Septal wall thickness, SWT _{sys} [cm]	0.7	0.9	1.0	1.1	1.2	1.3	1.4
	Septal wall thickness, SWT _{dia} [cm]	0.5	0.6	0.7	0.8	0.9	1.0	1.1
	Posterior wall thickness, PWT _{sys} [cm]	0.9	1.1	1.2	1.4	1.5	1.7	1.8
	Posterior wall thickness, PWT _{dia} [cm]	0.5	0.6	0.7	0.8	0.9	1.0	1.1
	LV inner diameter, LVID _{sys} [cm]	2.0	2.3	2.5	2.8	3.1	3.3	3.6
	LV inner diameter, LVID _{dia} [cm]	3.4	3.8	4.0	4.4	4.7	5.0	5.3
	Relative wall thickness (RWT)	0.22	0.28	0.33	0.38	0.43	0.48	0.54
LA dimension	LA anterior posterior diameter, LAD _{sys} [cm]	2.6	2.9	3.2	3.5	3.8	4.1	4.4
Global LV function	End-systolic volume, ESV [ml]	17	25	32	40	48	55	63
	End-diastolic volume EDV [ml]	102	106	111	115	120	124	129
	Stroke volume, SV [ml]	40	52	64	76	88	99	112
	Ejection fraction, EF [%]	52	57	61	66	71	75	80
LV myocardial mass parameters	LV myocardial mass, LVMM [g]	73	92	109	129	148	165	184
	LV mass index, LVMMI [g/m ²]	42	51	59	68	77	85	94

LV: left ventricle, LA: left atrium, sys: end-systole, dia: end-diastole

LV and LA dimensions

LV and LA dimensional measurements are important determinants for diagnosis, therapeutic decision making, and prognosis. The LV size predicts adverse cardiovascular events, including death, recurrent infarction, ventricular arrhythmias, and mitral regurgitation [30]. Concentric remodeling that is distinct from LV hypertrophy independently predicts adverse cardiovascular events in patients with a preserved EF [31]. LA size is a marker of the severity and chronicity of diastolic dysfunction [32], and enlargement of the LA diameter represents an independent predictor of clinical cardiovascular events in middle-aged and elderly adults [33].

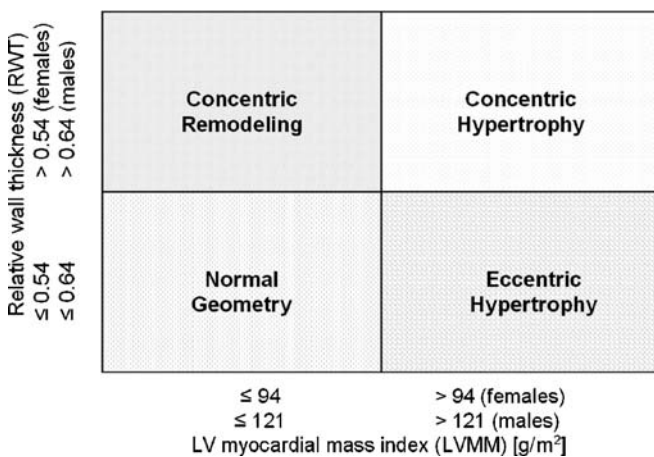


Fig. 4 Relative wall thickness (RWT) and left ventricular myocardial mass index (LVMMI) allowing the categorization of left ventricular hypertrophy as either concentric or eccentric. Concentric remodeling is defined as normal left ventricular mass with increased RWT

We found significant differences for all LV dimensions between men and women. Similar gender-specific differences were found regarding LV dimensions using MRI [20] and echocardiography [17]. Our CT data regarding SWT_{dia}, PWT_{dia}, LVID_{dia}, LAD_{sys}, and RWT are comparable to the reference values reported for echocardiography [17]. The PWT_{sys} and PWT_{dia} values from our study are similar to those reported for MRI [21].

Global LV function

Global LV functional parameters provide important information to diagnose heart failure [1, 2, 34] and allow to identify patients who are at risk of developing congestive heart failure or death after valve replacement [35]. In the evaluation of dilated cardiomyopathy, analysis of global LV function shows diminution in systolic function with increased ESV and EDV, resulting in a decreased EF [36]. LV volumes and EF provide valuable diagnostic information and are of long-term prognostic importance for patients [11, 12, 37].

Global LV function as assessed with CT was shown to be highly accurate [38] and provides a high correlation with measurements from MRI [11–13]. It is important to note, however, that small differences between CT and MRI regarding measurements of EDV and ESV [11, 12] have been repetitively reported. This reinforces the need for modality-specific reference values. The assessment of global LV function with 64-slice CT has recently shown an excellent correlation with single photon emission CT [20].

We found significant differences for global LV functional parameters, including ESV, EDV, and SV between males and females, whereas no significant differences were

found for the EF. In addition, a tendency towards a decrease in SV with an increase in the age of women could be demonstrated. These gender- and age-dependent findings are similar to those reported in MRI [18]. ESV, EDV, and SV values in this study were similar to those reported for MRI [17], whereas our ESV and EDV values are higher than those reported in echocardiography [12]. However, the three-dimensional capabilities of CT and MRI have been shown to surpass the accuracy of two-dimensional modalities, such as echocardiography [39].

Myocardial mass

Myocardial mass parameters provide important information regarding diagnosis, risk stratification, and prognosis, and the LVMM significantly correlates with cardiovascular morbidity and mortality, while regression of LV myocardial mass reduces the risk of cardiovascular events [40].

A recent study showed an excellent agreement regarding LVMM values between 16-slice CT and MRI [21]. Our CT reference values for LVMM and LVMMI are similar to those reported for MRI [17] and in echocardiography [18, 21], and show significant differences between men and women. These gender-specific differences have been similarly reported for MRI [41] and echocardiography [21].

No significant correlations between LVMM, LVMMI, and age in MRI in a population from 22 to 74 years of age have been reported [42]. Our CT data also showed no significant correlation in a population with a higher age range. This is supported by the Framingham study showing LVMM to remain relatively stable in healthy men and women with advancing age [11, 12, 37].

Study limitations

The following study limitations need to be addressed. First, most of our subjects did not have prior echocardiography or MRI to verify normal cardiac dimensions and function. Hence, there still remains an uncertainty of cardiac health.

To minimize this potential bias, we used strict inclusion and exclusion criteria. Second, we used two different CT scanner generations. However, several studies have shown an excellent correlation regarding global LV function even when using 16-slice CT and MRI [11, 12]. The CT scanners used in this study are characterized by a higher temporal and spatial resolution, most probably yielding even more accurate results. Third, no evaluation of the right ventricle and right atrium were performed. This would require relatively homogenous contrast attenuation in the right heart that is challenging with CT. Fourth, the papillary muscles were included into volume measurements as part of the LV cavity. On the other hand, the impact of inclusion or exclusion of papillary muscles on global LV function assessment has been shown to be negligible [43]. Fifth, dimensional measurements were obtained at the chorda level. As tendinous chords are small and linear structures, measurements could differ considerably when changing the orientation or position of the imaging plane only a few millimeters towards the cardiac apex or base. On the other hand, the same is true also for echocardiography and MRI. Finally, the high inter- and intra-class correlation coefficients in our study indicate a relatively high degree of reliability for such measurements.

Conclusion

Important clinical management decisions rely on quantitative values characterizing dimensions, global function, and myocardial mass of the left heart. This study provides gender-related reference values and percentiles for LV and LA quantitative measurements for cardiac CT, the modality that is increasingly used for non-invasive imaging of the heart. Knowledge of normal distribution of left heart measurements and differences that exist between genders should assist in correct interpretation of disease states with cardiac CT.

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